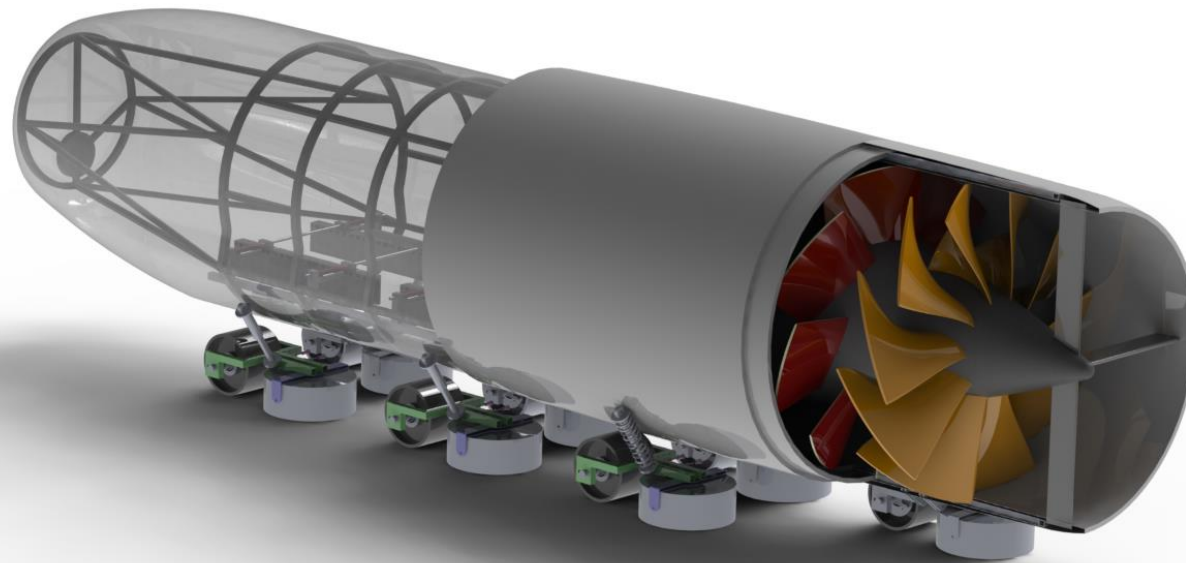


Contra-Rotating Fan Design for the Hyperloop Pod



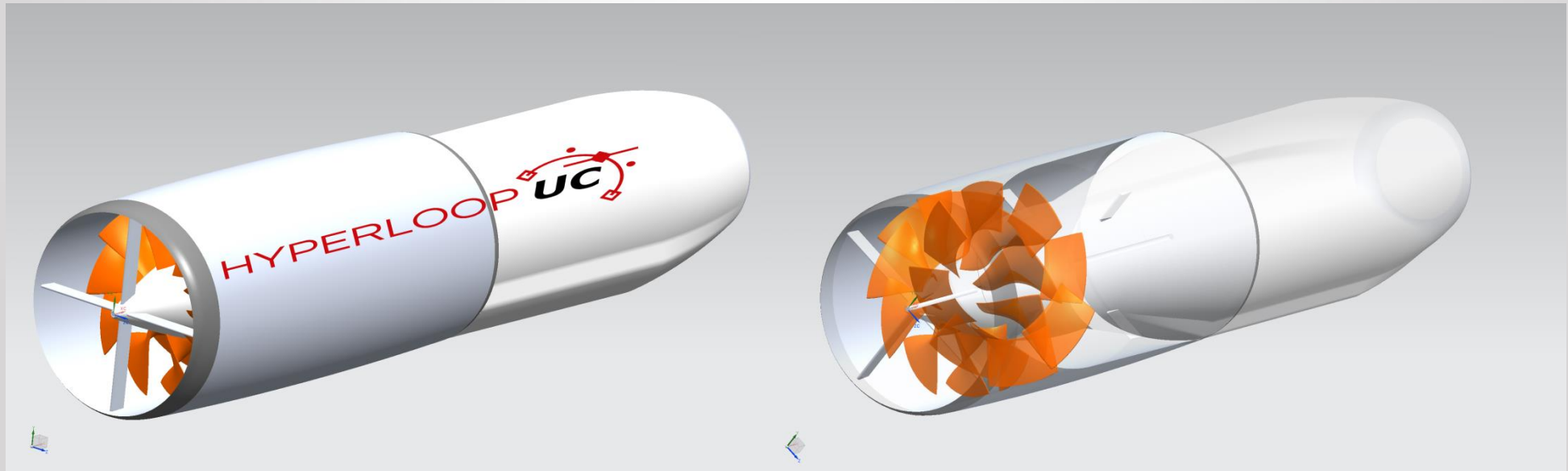
Kiran Siddappaji

Dr. Mark G. Turner

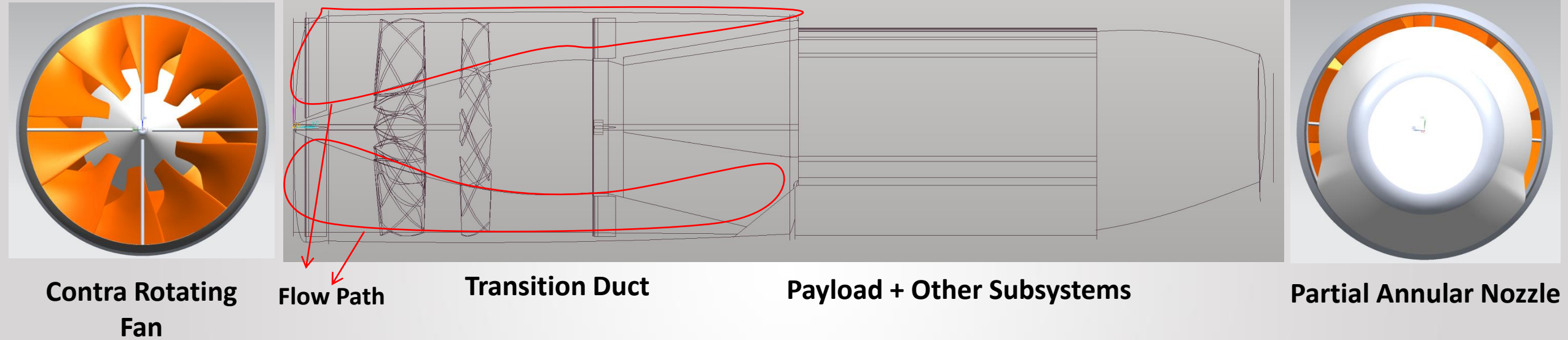
Dr. Shaaban Abdallah

Contra Rotating FAN concept

- **Contra Rotating Fan + Duct + Nozzle**
- Fan is used to bypass the mass flow to the exit nozzle.
- A transition duct from the exit of fan leads to the nozzle.
- Pressure Vessels have ducts with control valves for cooling.
- Below is the pod configuration **without** the base skirt, hoverboards and brake wheels.



TURBOFAN concept



This is the pod configuration **without** the base skirt, hoverboards and brake wheels.

Inlet condition for the design :

$\dot{m} = 0.474 \text{ kg/s}$

$P_t = 522 \text{ Pa}$; $P_s = 500 \text{ Pa}$

$T_t = 316.674 \text{ K}$

$M = 0.25$

$RPM1 = 4900$; $RPM2 = -5100$

10 blades, 8 blades

Pressure Ratio : 1.3 ; Eff. : 75%

Power : 10 kW

The front rotor and the aft rotor spin in opposite directions. **The benefits are higher pressure ratio, torque balance, lower rpm and power required as compared to a single stage fan.**

Contra Rotating FAN Design Process

- A 1D meanline design and analysis was performed on a single stage Fan.
- A 2D Radial Equilibrium design and analysis was performed on that design point.
- The efficiency was optimized in 2D radial equilibrium calculation.
- The stator was converted into a rotor spinning in the opposite direction by giving a negative RPM.
- An axisymmetric simulation on the counter rotating design was calculated.
- From this, 3D blade shapes were obtained and a 3D CFD analysis was performed.
- Once a satisfactory pressure ratio was obtained the design was frozen.
- Need to optimize the shape in 3D.

Single Stage (SS) FAN : 1D Meanline Design

Inlet condition for the design :

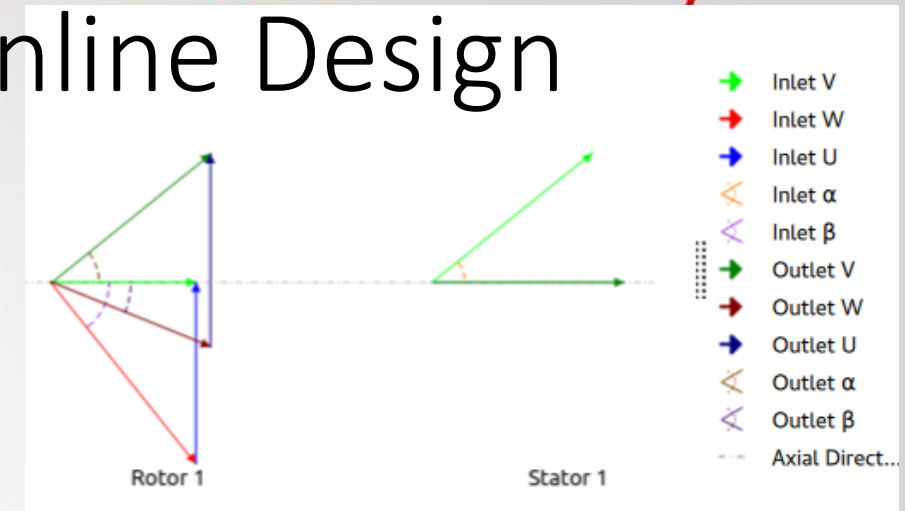
$\dot{m} = 0.474 \text{ kg/s}$

$P_t = 522 \text{ Pa}$; $P_s = 500 \text{ Pa}$

$T_t = 316.674 \text{ K}$

$M = 0.25$

Power : 14.74 kW



AutoDesign meanline general quantity

Selected quantity: Total-to-total pressure ratio

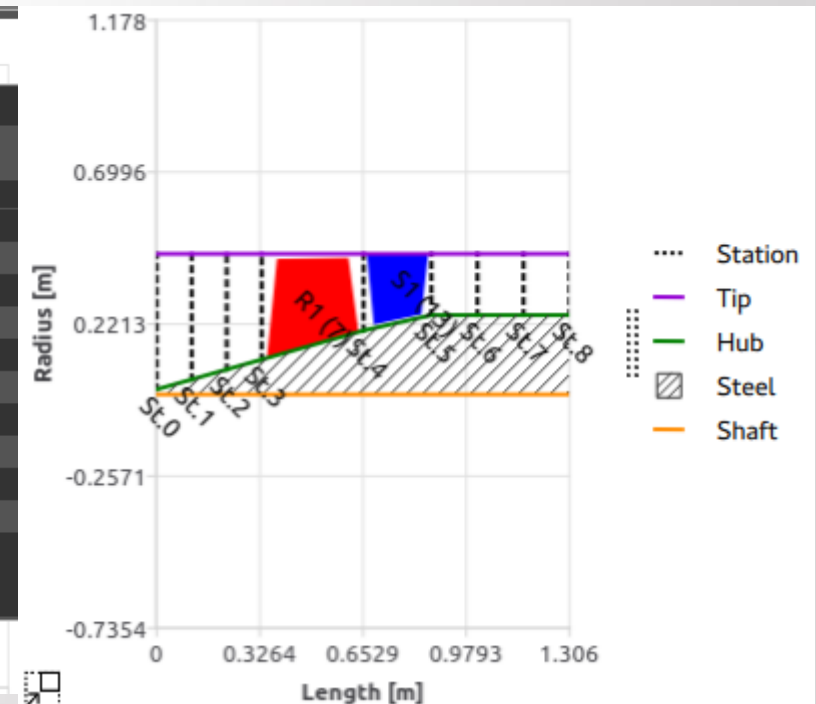
Maximum axial Mach number	0.5925
Maximum relative Mach number	0.8614
Maximum tip radius	0.4425 m
Minimum hub radius	1.5838 cm
Total length	130.579 cm
Total-to-total isentropic efficiency	0.6317
Total-to-total pressure ratio	1.2334

AutoDesign meanLine quantity table

AutoDesign meanline quantity table

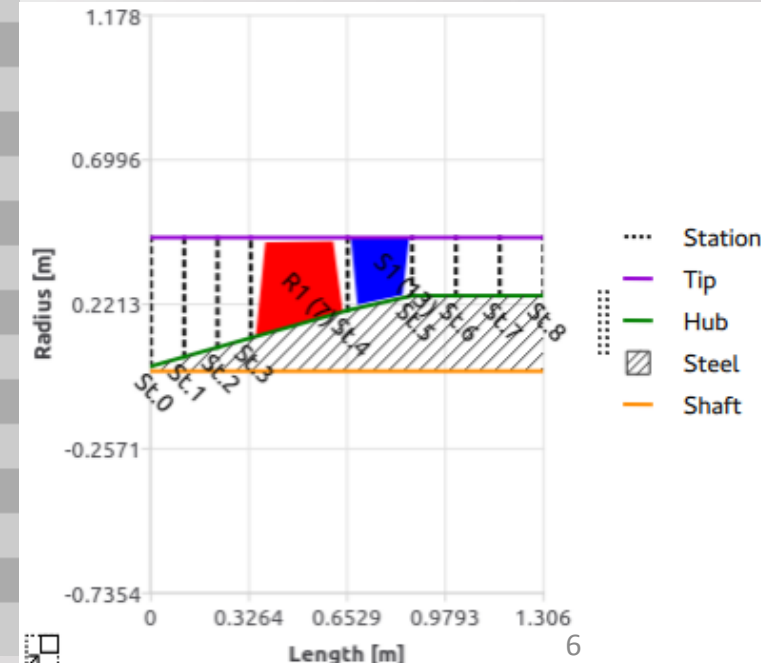
Machine Rows Sections Inlets-Outlets

Quantity	machine
Flow coefficient	0.8
Fluid	AIR
Exit angle [rad]	0.0
Inlet tip radius [m]	0.45
Inlet hub radius [cm]	11.0
Inlet total pressure [Pa]	522.219
Inlet total temperature [K]	316.674
Mass flow rate [kg/s]	0.474
Total-to-total pressure ratio	1.2334
Rotational speed [rpm]	6000.0
ICV	False



SS FAN : 1D Meanline Design

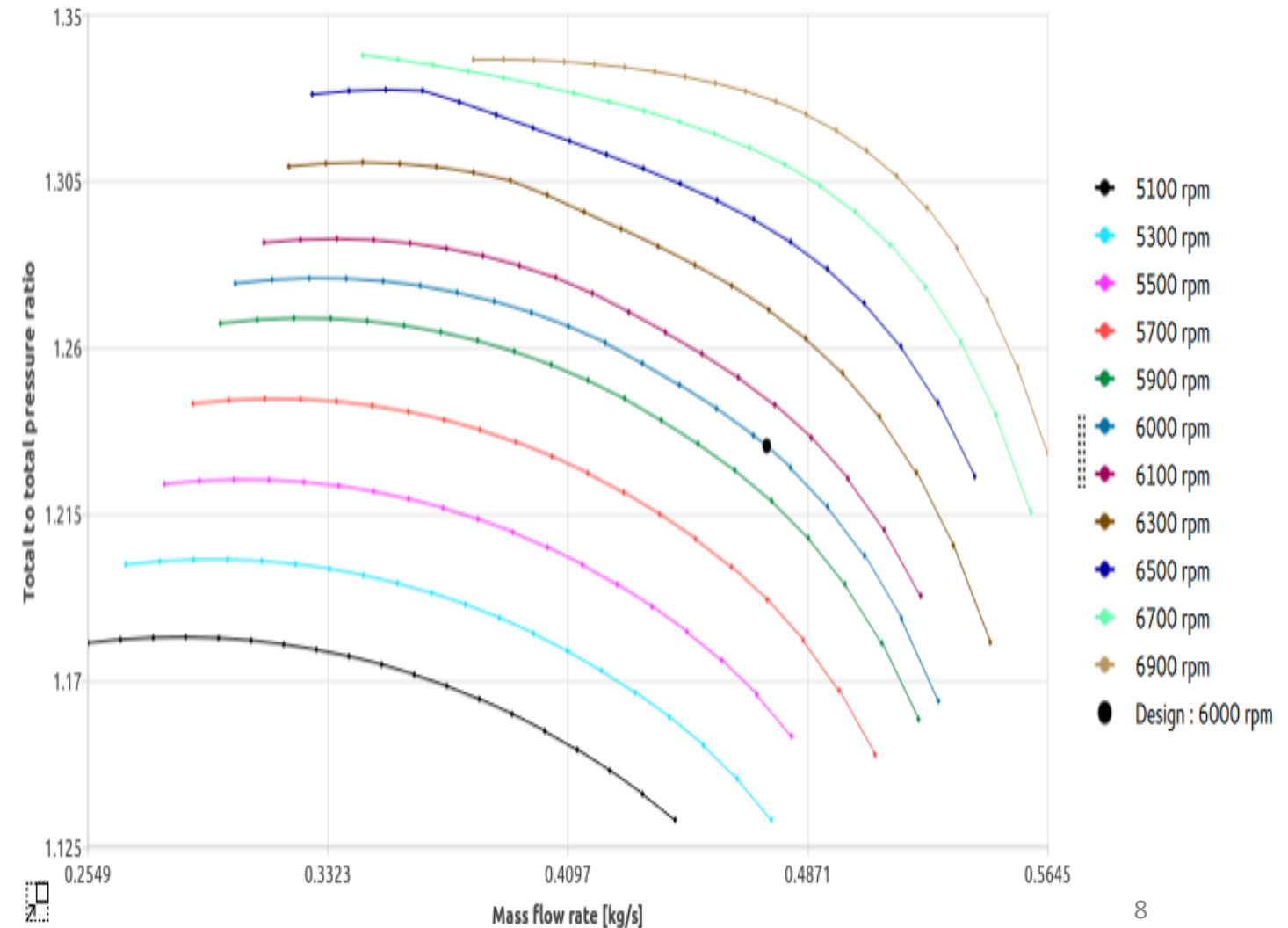
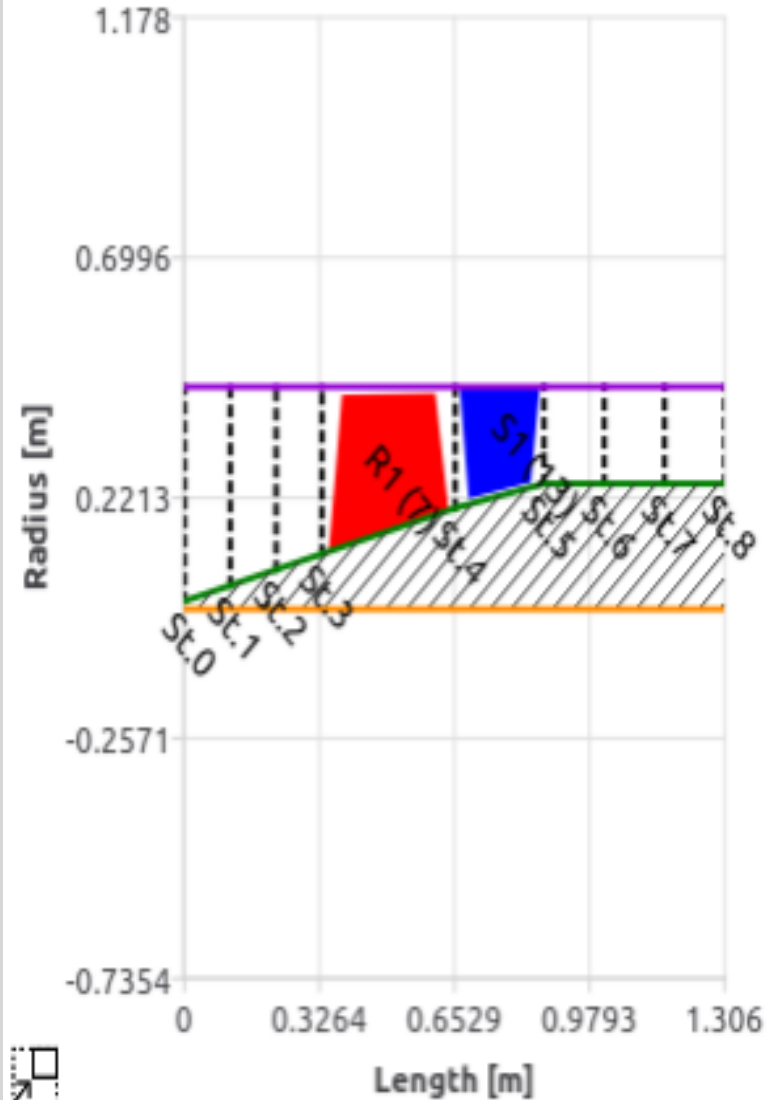
Quantity	Inlet Extension 3	Rotor 1	Stator 1	Outlet Extension 1
Blockage	Wright & Miller	Wright & Miller	Wright & Miller	Wright & Miller
Deviation correlation	NASA-SP36-2D cascade	NASA-SP36-2D cascade	NASA-SP36-2D cascade	NASA-SP36-2D cascade
Endwall loss model	Wright & Miller	Wright & Miller	Wright & Miller	Wright & Miller
Minimum loss incidence	NASA-Sp36-2D cascade	NASA-Sp36-2D cascade	NASA-Sp36-2D cascade	NASA-Sp36-2D cascade
Off-design deviation	Creveling	Creveling	Creveling	Creveling
Off-design loss model	Creveling	Creveling	Creveling	Creveling
Profile loss model	Wright & Miller	Wright & Miller	Wright & Miller	Wright & Miller
Shock loss model	Wright & Miller	Wright & Miller	Wright & Miller	Wright & Miller
Annulus layout	Constant mean radius	Constant tip radius	Constant tip radius	Constant mean radius
Area inlet [m ²]	0.5772	0.5772	0.488	0.4191
Area outlet [m ²]	0.5772	0.488	0.4191	0.4191
Blade height [m]	0.3325	0.2917	0.2182	0.1927
Clearance absolute [m]	0.0	0.0029	0.0	0.0
Clearance relative	0.0	0.01	0.0	0.0
Hub to tip ratio	0.2486	0.2486	0.4547	0.5646
Mass flow rate [kg/s]	0.474	0.474	0.474	0.474
Number blades	0.0	8.0	14.0	0.0
Rotating row	False	True	False	False
Rotational speed omega [rad/s]	0.0	628.318	0.0	0.0



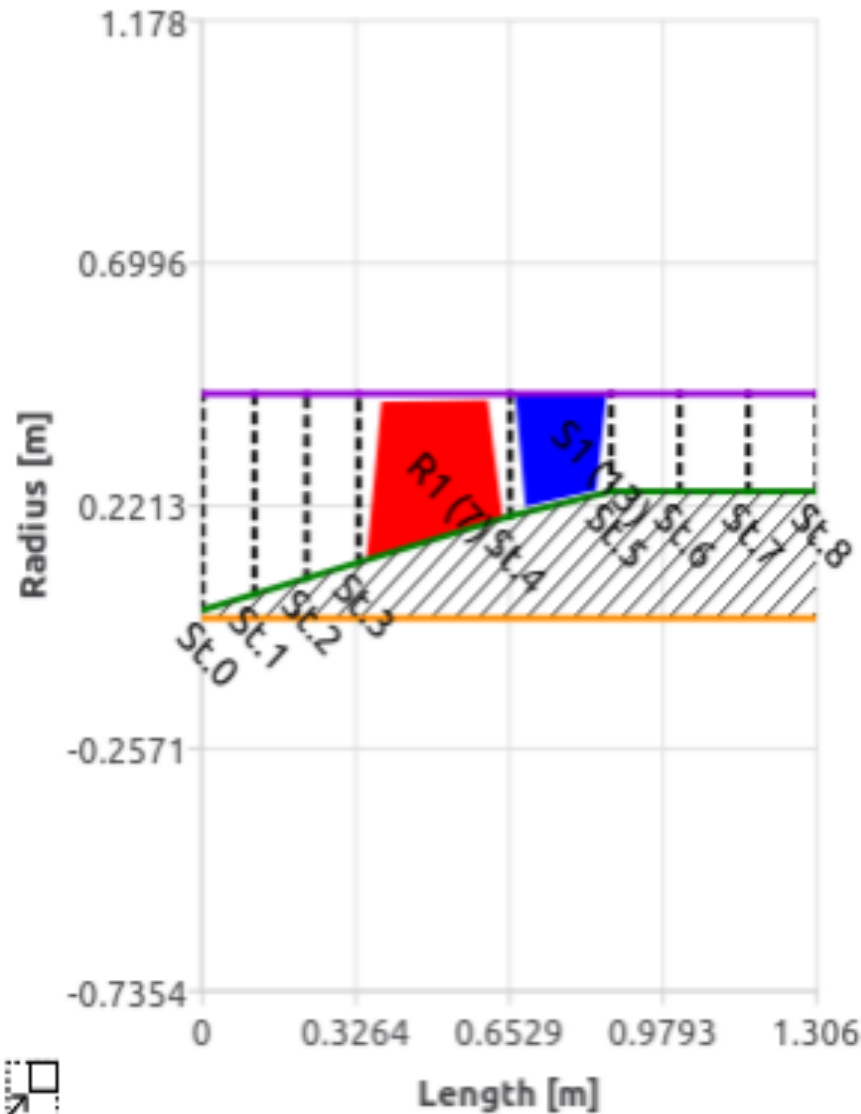
SS FAN : 1D Meanline Design

Quantity ▼	Rotor 1 – Hub	Rotor 1 – Mid	Rotor 1 – Tip	Stator 1 – Hub	Stator 1 – Mid	Stator 1 – Tip
End Wall loss omega	0.1219	0.1219	0.1219	0.1177	0.1177	0.1177
Flow coefficient	2.3449	0.8	0.5829	1.4102	0.8255	0.6412
Profile loss omega	0.4148	0.0814	0.0771	0.1478	0.0955	0.093
Load coefficient	3.2534	0.71	0.4023	0.0	0.0	0.0
Stage reaction	-0.0616	0.578	0.7102	-0.0616	0.578	0.7102
Shock loss omega	0.0	0.0	0.0	0.0	0.0	0.0
Turning [rad]	0.9939	0.5123	0.2927	0.9436	0.6794	0.5603
Aspect ratio	1.1188	1.1188	1.1188	1.3848	1.3848	1.3848
Camber angle [rad]	-1.1149	-0.9437	-0.8331	1.3802	1.117	1.0211
Camber curvature radius [m]	0.2464	0.2868	0.3222	0.1238	0.1487	0.1612
Center of gravity absolute [m]	0.4767	0.4767	0.4767	0.7565	0.7565	0.7565
Center of gravity relative meridian...	0.5259	0.4227	0.3813	0.4274	0.4641	0.4776
Chord [m]	0.2607	0.2607	0.2607	0.1576	0.1576	0.1576
Chord length arc [m]	0.2747	0.2707	0.2684	0.1708	0.1661	0.1647
Deviation [rad]	0.1455	0.2842	0.3234	0.306	0.313	0.3408
Incidence [rad]	0.0245	-0.1473	-0.217	-0.1306	-0.1247	-0.1201
Inlet metal angle [rad]	-0.3786	-1.0433	-1.2601	1.0742	0.8041	0.6804
Leading edge radius absolute [m]	0.0026	0.0026	0.0026	0.0016	0.0016	0.0016
Leading edge radius relative	0.01	0.01	0.01	0.01	0.01	0.01
Meridional chord [m]	0.2566	0.2193	0.1733	0.1461	0.1529	0.1553
Outlet metal angle [rad]	0.7363	-0.0996	-0.427	-0.306	-0.313	-0.3408
Pitch [m]	0.1185	0.2607	0.3475	0.1007	0.1576	0.1986
Slope	0.276	0.066	-0.0	0.2228	0.0725	-0.0
Solidity	2.201	1.0	0.7502	1.5656	1.0	0.7935

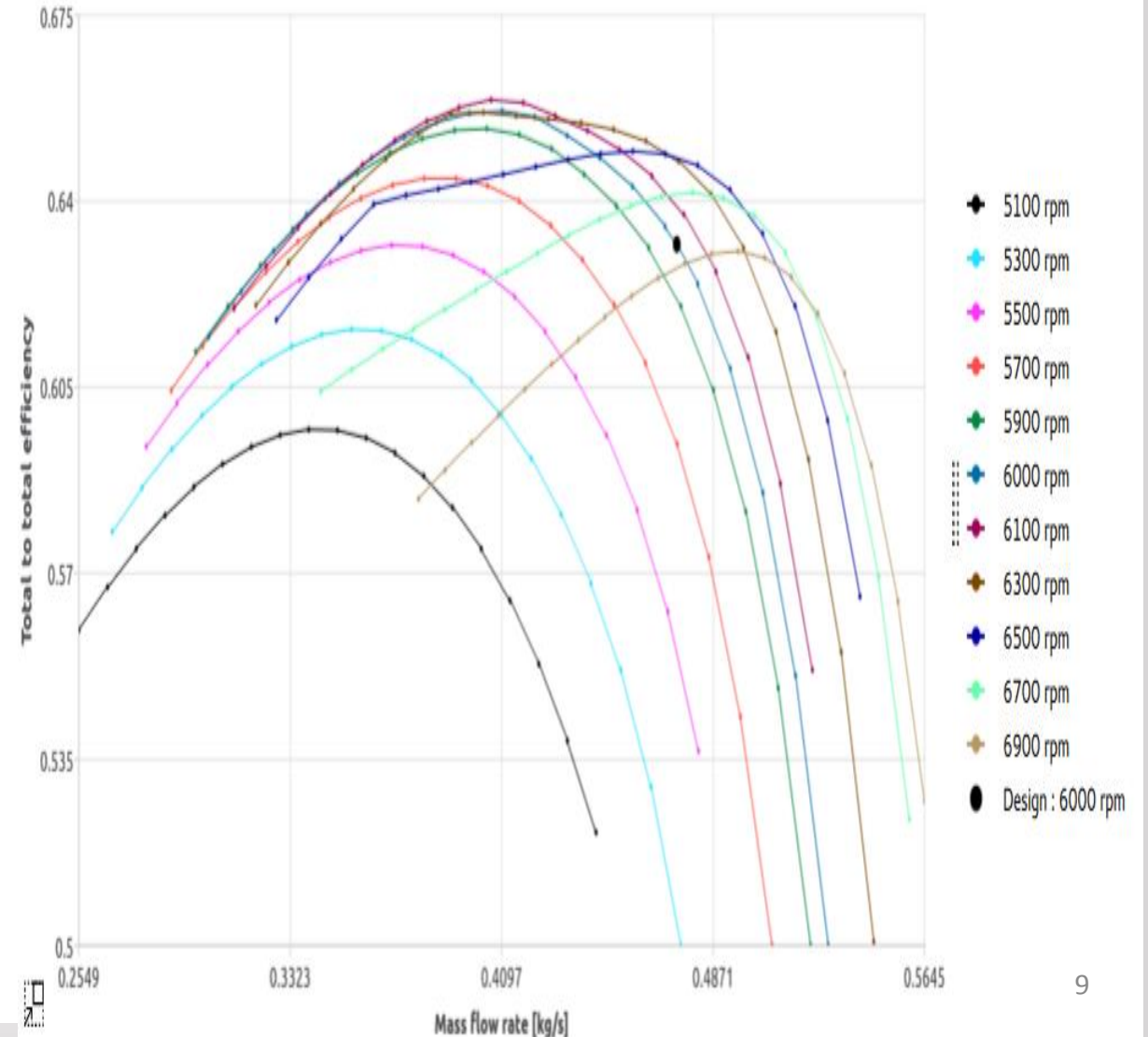
SS FAN : 1D Meanline Off Design



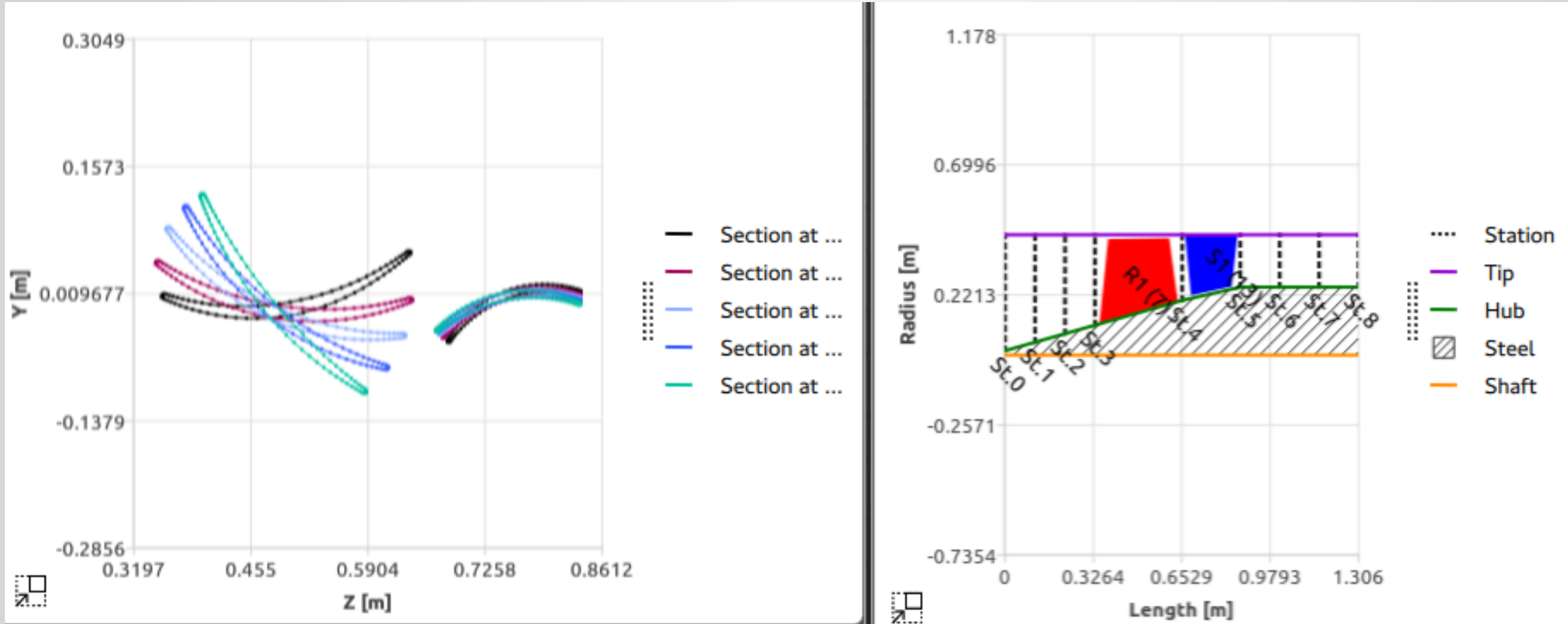
SS FAN : 1D Meanline Off Design



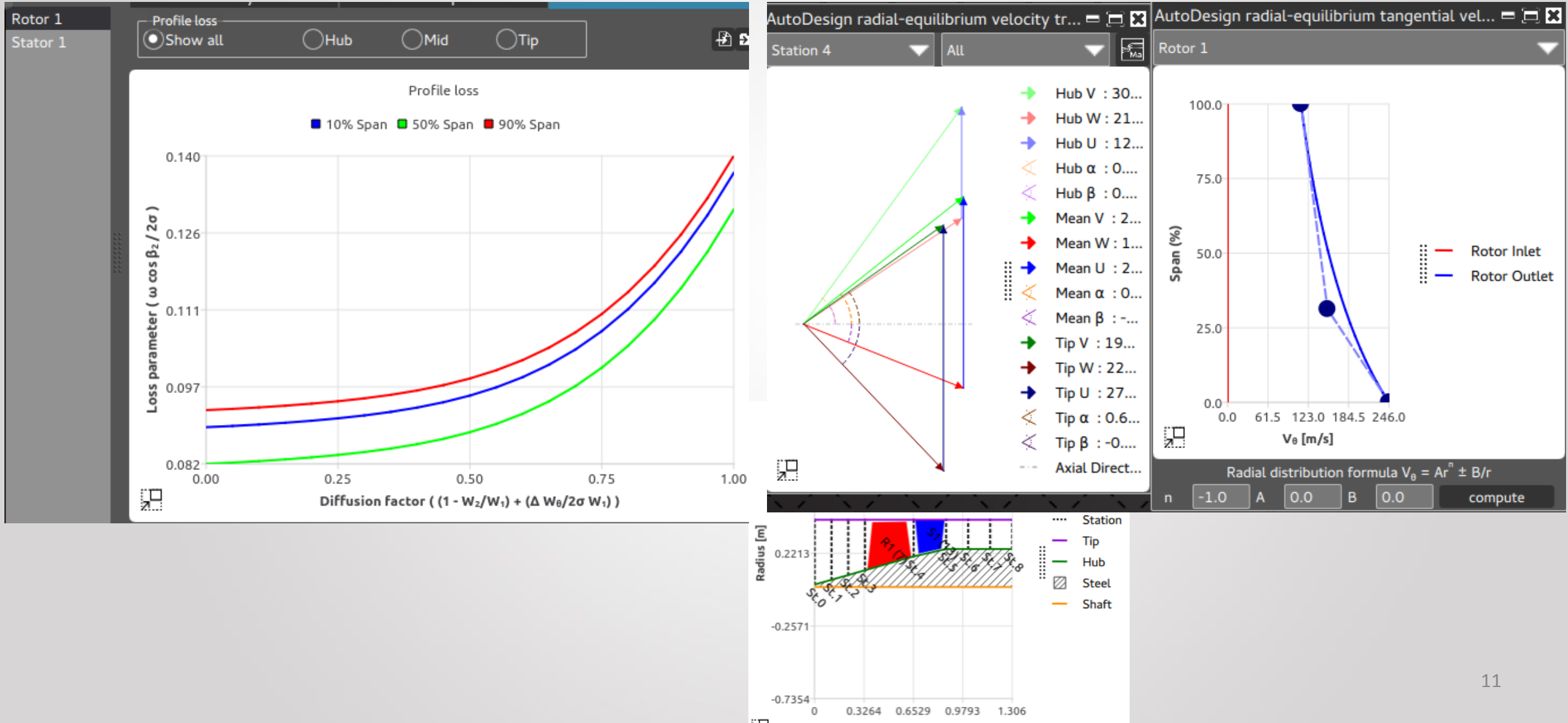
- Station
- Tip
- Hub
- ▨ Steel
- Shaft



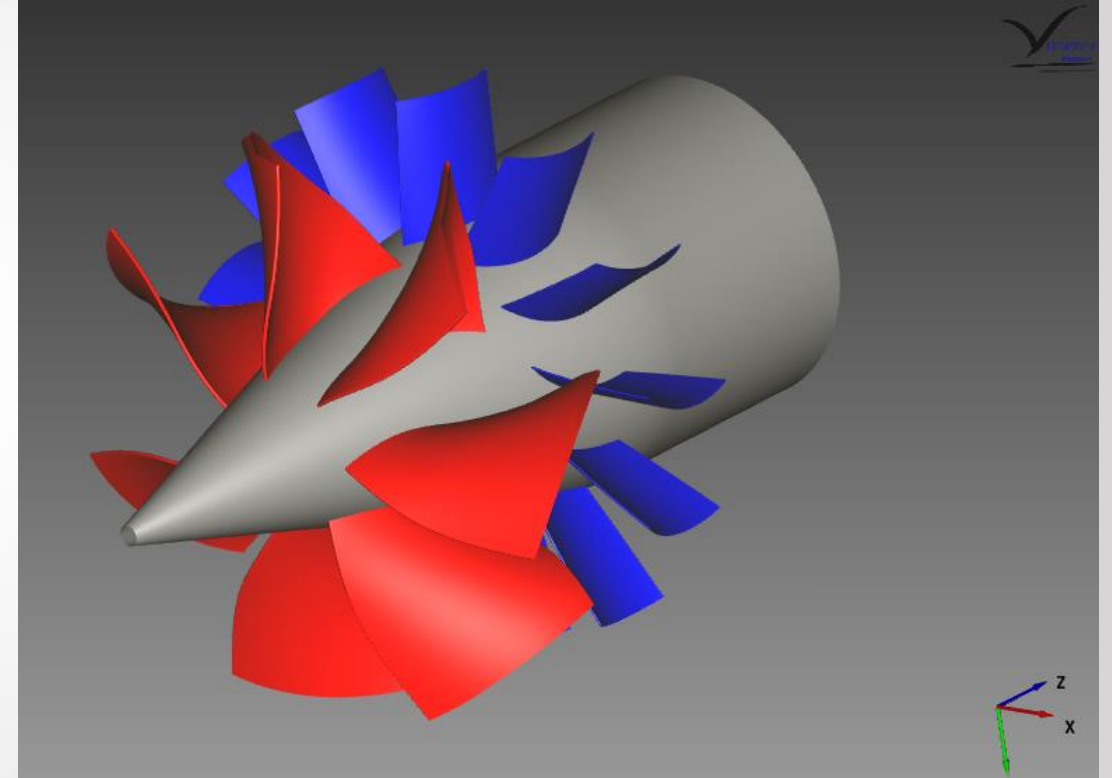
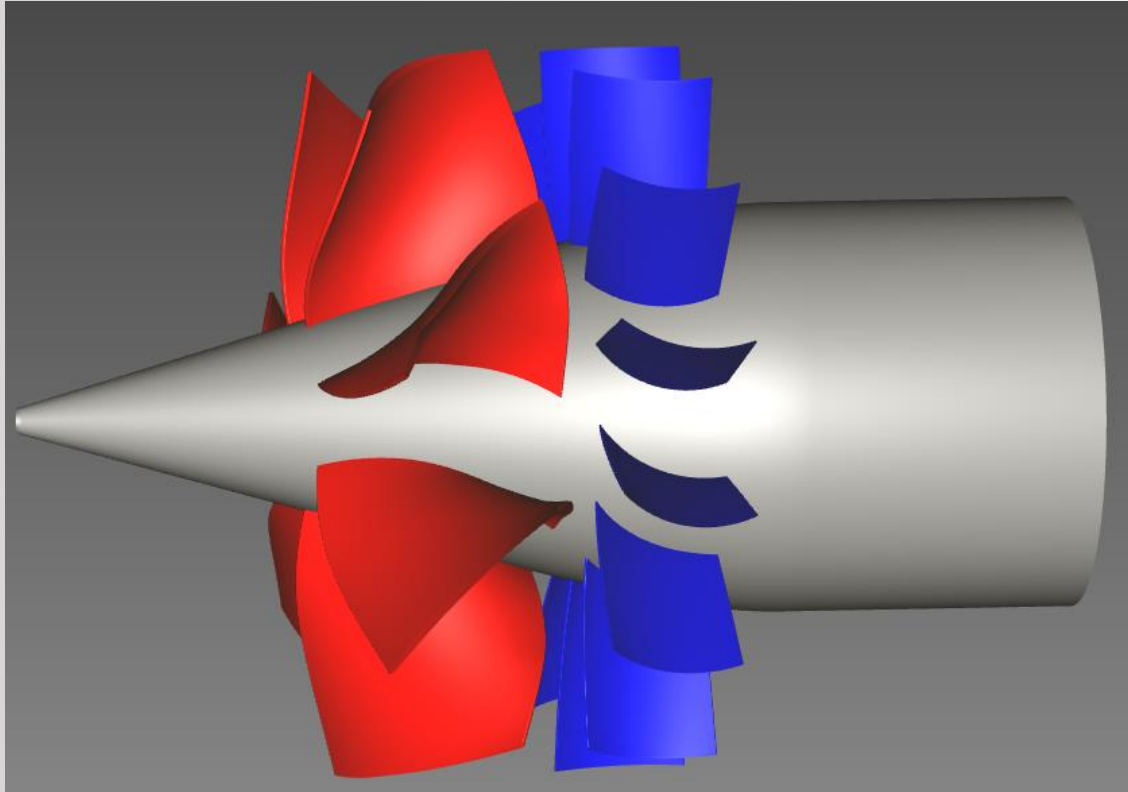
SS FAN : Radial Equilibrium Design (2D)



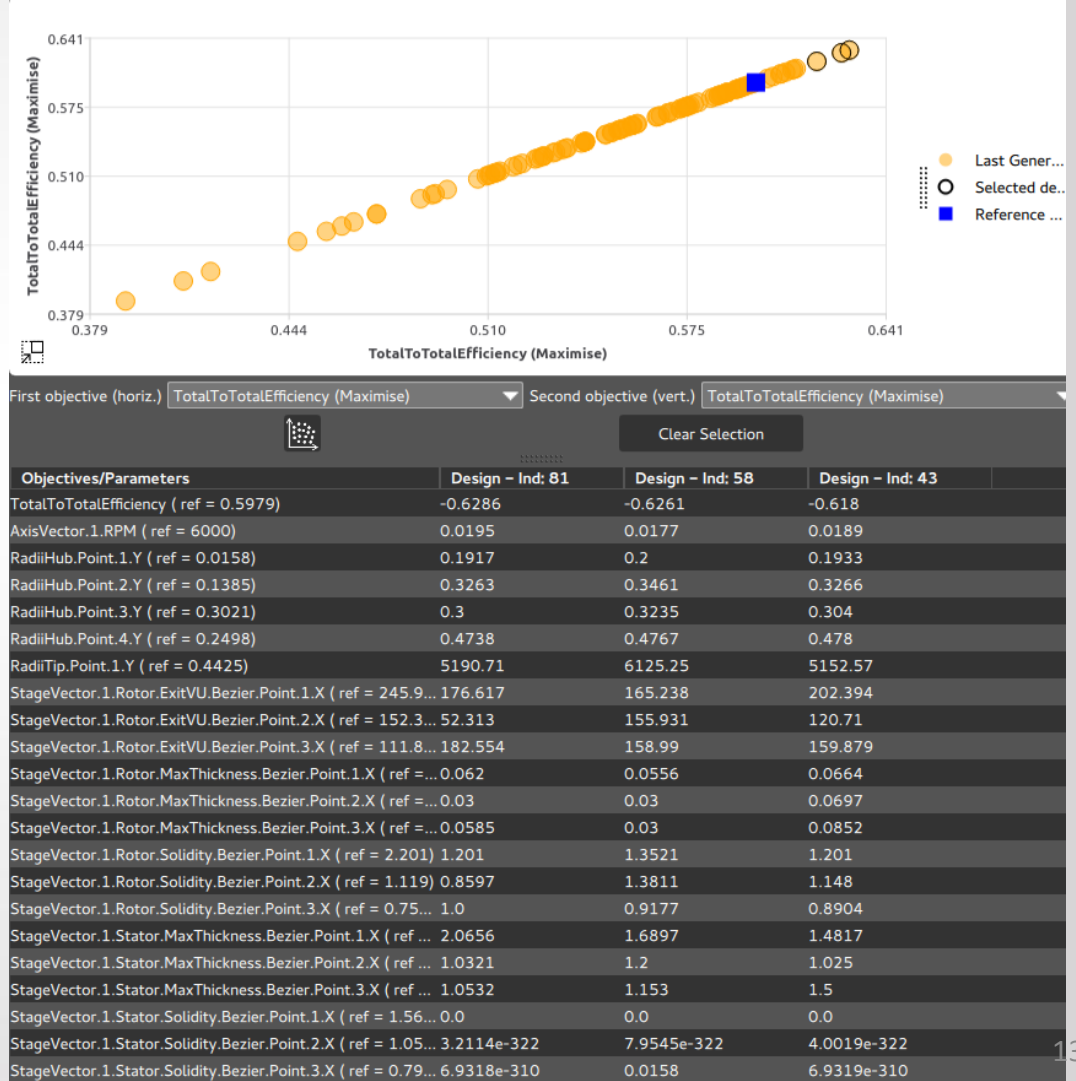
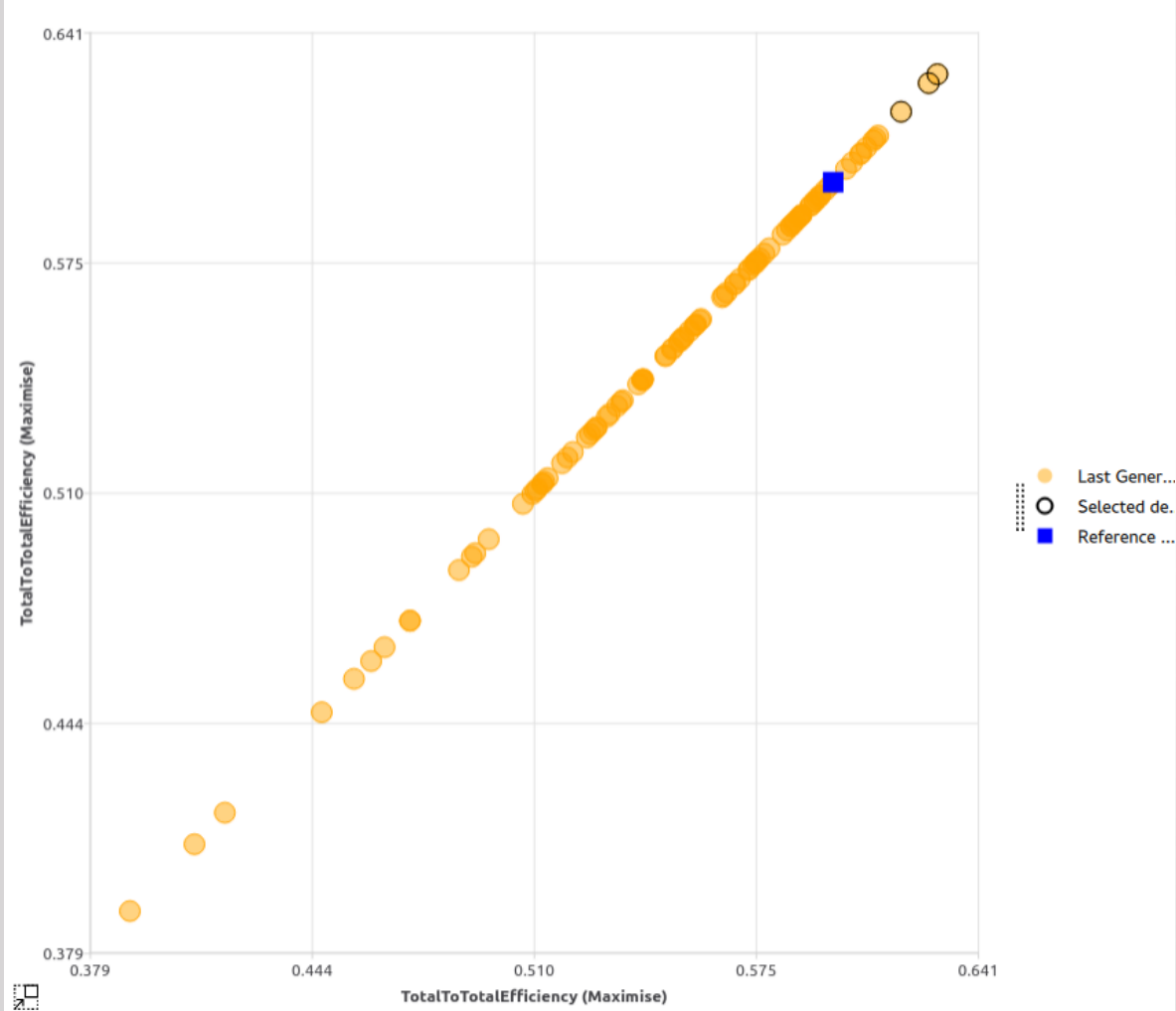
SS FAN : Radial Equilibrium Design (2D)



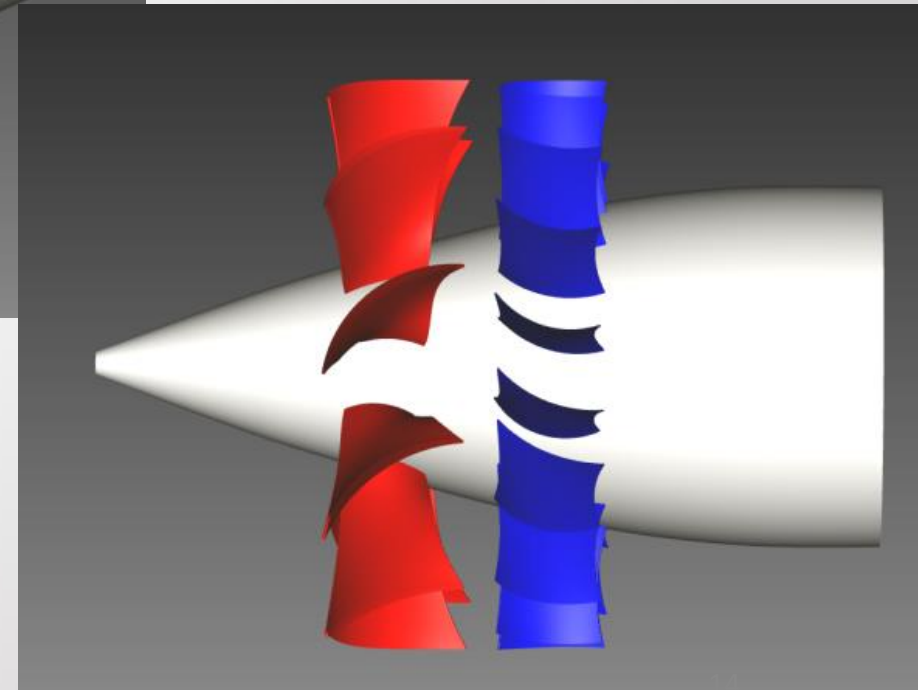
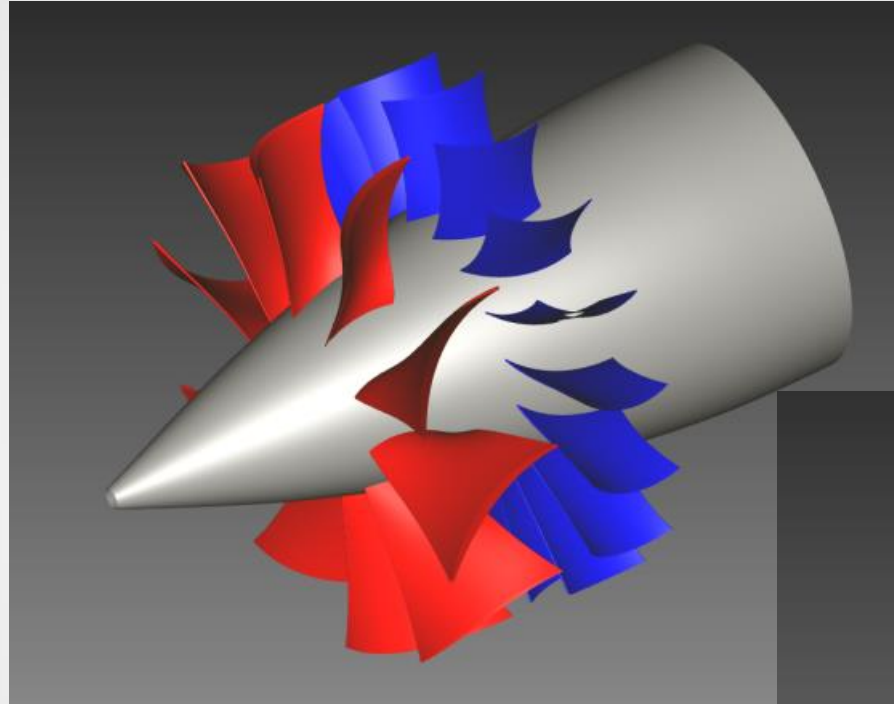
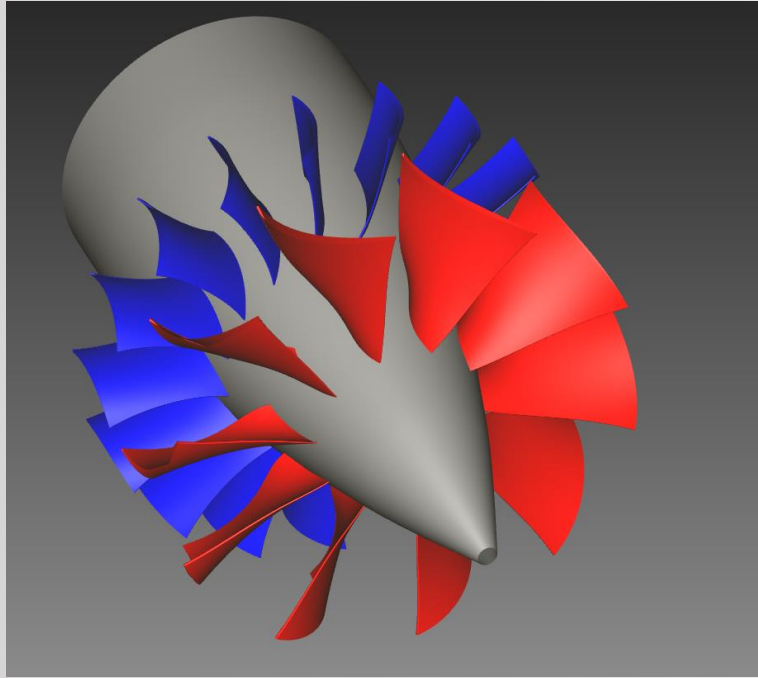
SS FAN : 3D Geometry



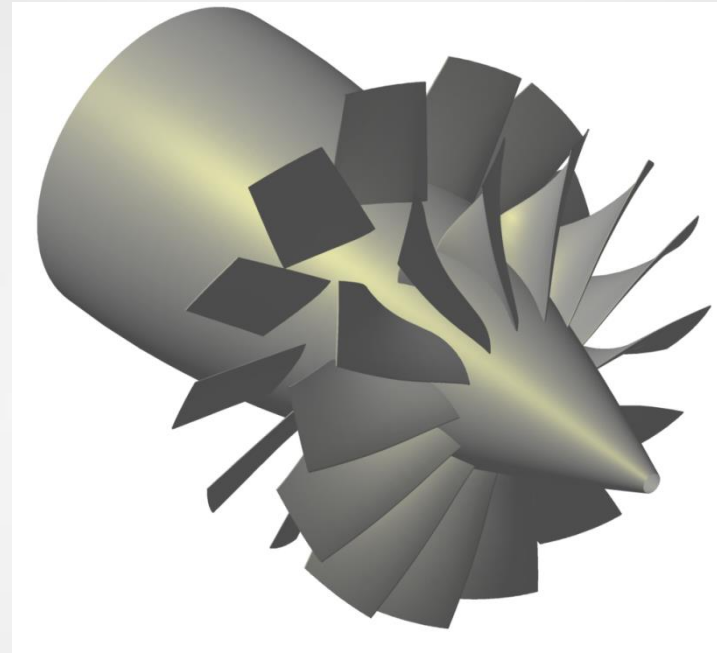
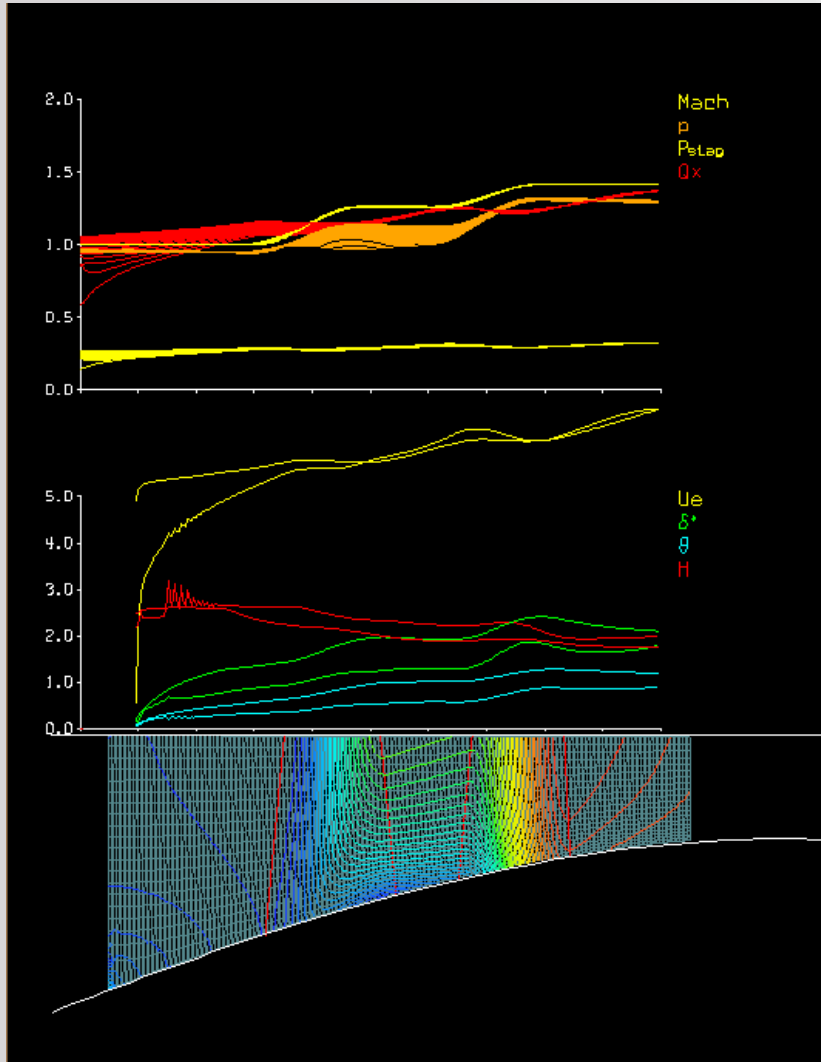
SS Fan Single Objective Optimization: Efficiency



Hyperloop FAN : Efficiency Optimized design



Contra Rotating (CR) Fan



Axisymmetric solution
of the counter rotating fan

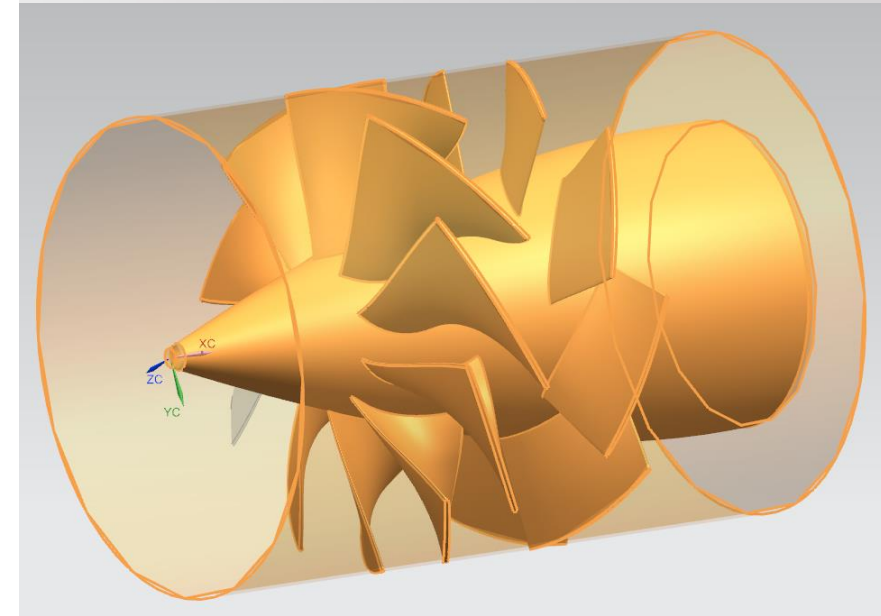
Overall Mass Averaged Performance

PR = 1.537

TR = 1.145

Eff (adiab.) = 0.901

Eff (poly.) = 0.907



3D Geometry

higher Pressure Ratio, Torque balance, lower RPM and Power required as compared to a single stage fan.

3D CFD of CR Fan

Mesh data

Number_of_blocks 18
Total_number_of_nodes 420610

Fluid properties

Fluid_type Perfect gas
Specific_heat (Cp) 1006.0 [J/(kg K)]
Specific_heat_ratio 1.4000 []

Weight factors used for averaging

For static pressure cell face area
For all other variables absolute cell face mass flux

*
* GLOBAL RESULTS AT INLET AND OUTLET
*

	INLET	OUTLET	
Geometrical data -----			
Hub_radius	0.19501E-01	0.30000	[m]
Shroud_radius	0.47380	0.47380	[m]
Area	0.70400E-01	0.52808E-01	[m2]
Number_of_blades	10	8	
Rotational_speed	-513.28	534.97	[rad/s]

Inlet condition for the design :

$\dot{m} = 0.474 \text{ kg/s}$

Pt = 522 Pa; Ps = 500 Pa

Tt = 316.674 K

M = 0.25

RPM1 = 4900; RPM2 = -5100

10 blades, 8 blades

Pressure Ratio : 1.3 ; Eff. : 75%

Power : 10 kW

Absolute velocities

Radial_velocity	0.32203E-08	-1.6507	[m/s]
Absolute_tangential_velocity	0.20159E-10	-51.178	[m/s]
Axial_velocity	76.342	127.04	[m/s]
Absolute_velocity_magnitude	76.342	137.90	[m/s]
Meridional_flow_angle	0.24169E-08	-0.74441	[deg]
Absolute_blade-to-blade_flow_angle	0.15129E-10	-21.940	[deg]
Absolute_Mach_number	0.21485	0.37625	[]
Swirl	0.24748E-10	-20.428	[m2/s]

Relative velocities

Relative_tangential_velocity	163.37	-262.40	[m/s]
Relative_velocity_magnitude	182.23	291.89	[m/s]
Relative_blade-to-blade_flow_angle	64.954	-64.164	[deg]
Relative_Mach_number	0.51284	0.79640	[]

Static conditions

Static_pressure	505.77	564.39	[Pa]
Static_temperature	313.77	333.82	[K]
Density	0.56067E-02	0.58848E-02	[kg/m3]

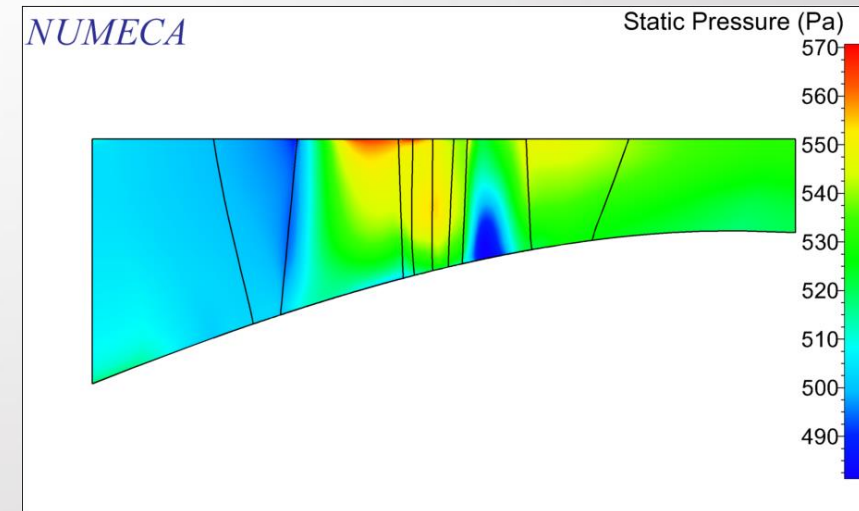
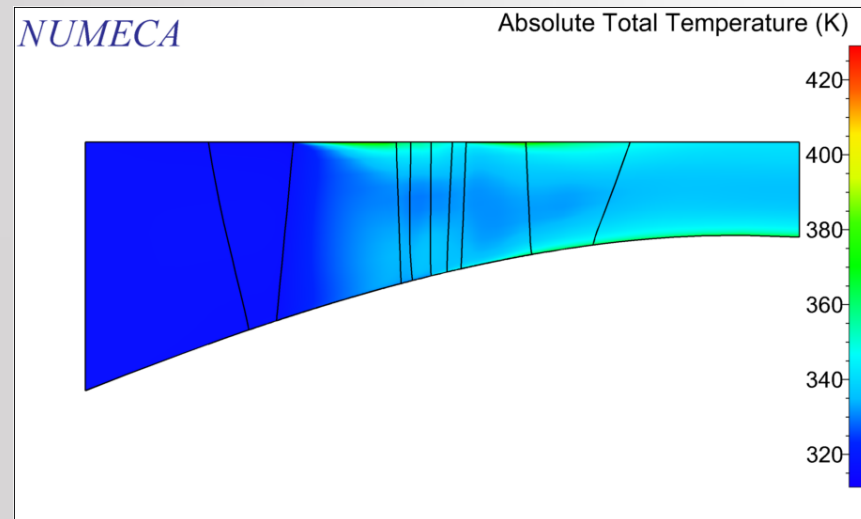
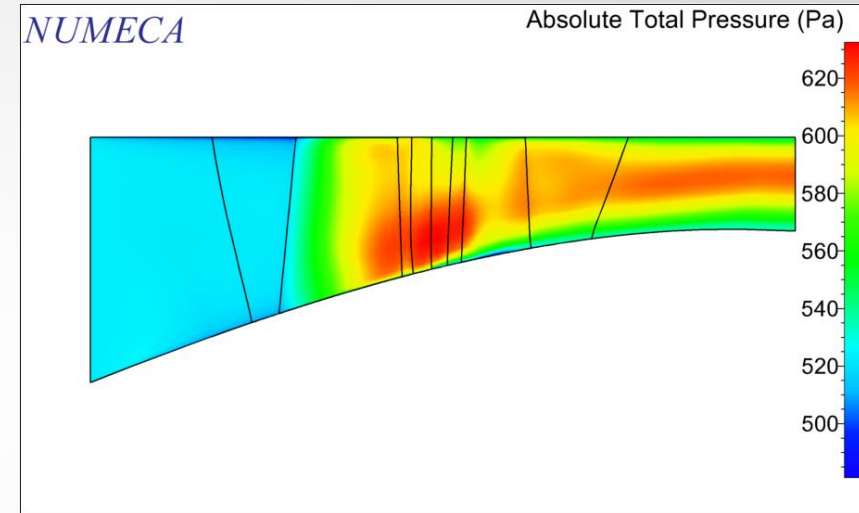
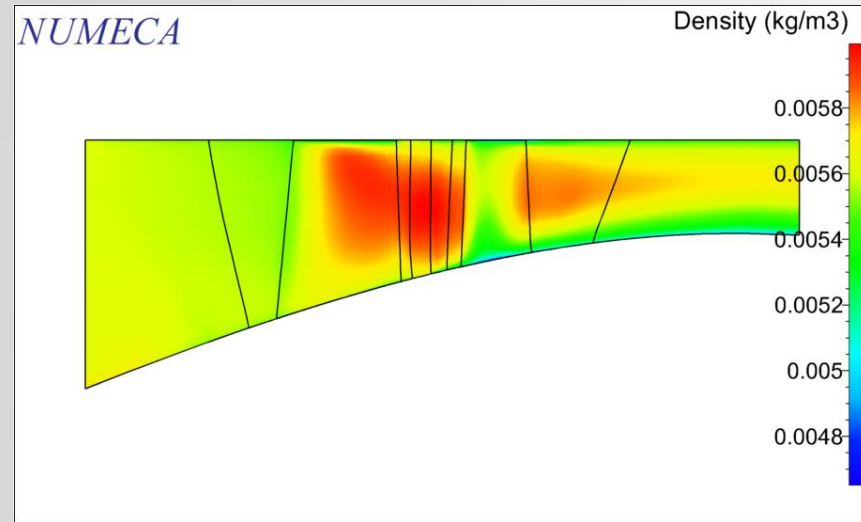
Total conditions

Absolute_total_pressure	522.22	624.35	[Pa]
Absolute_total_temperature	316.67	343.50	[K]
Relative_total_pressure	614.43	866.01	[Pa]
Relative_total_temperature	331.47	376.82	[K]

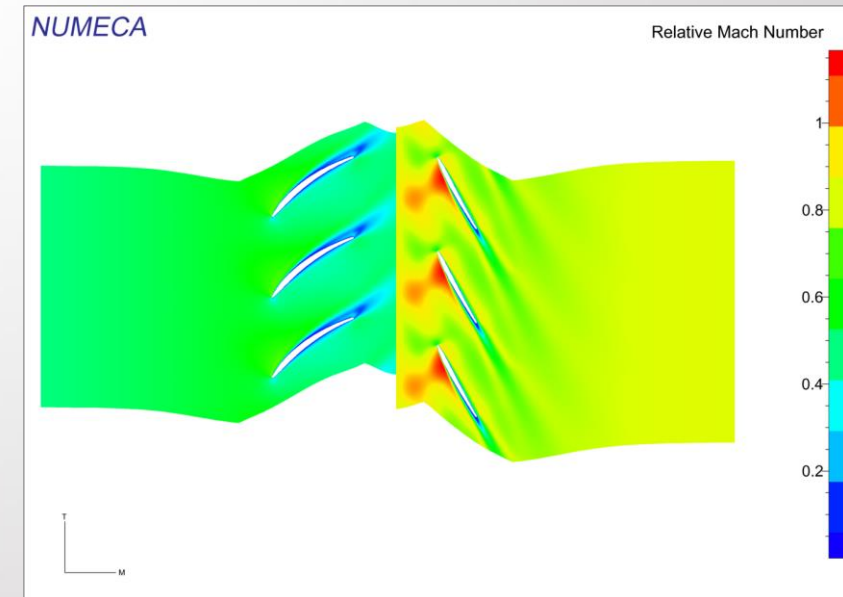
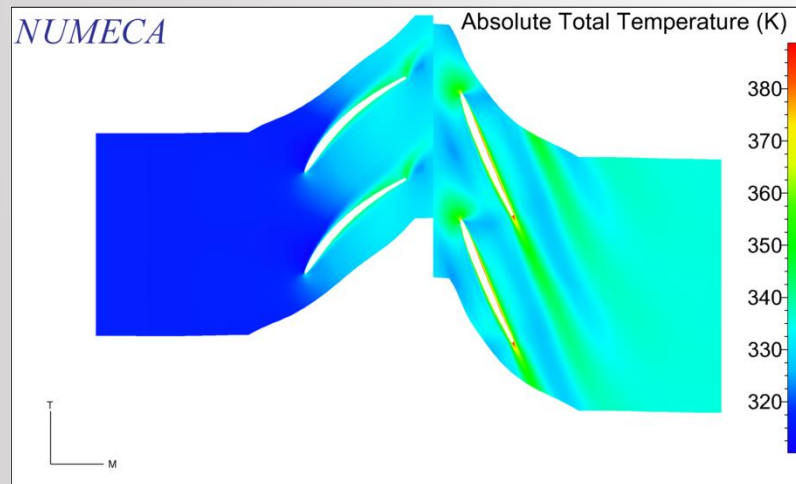
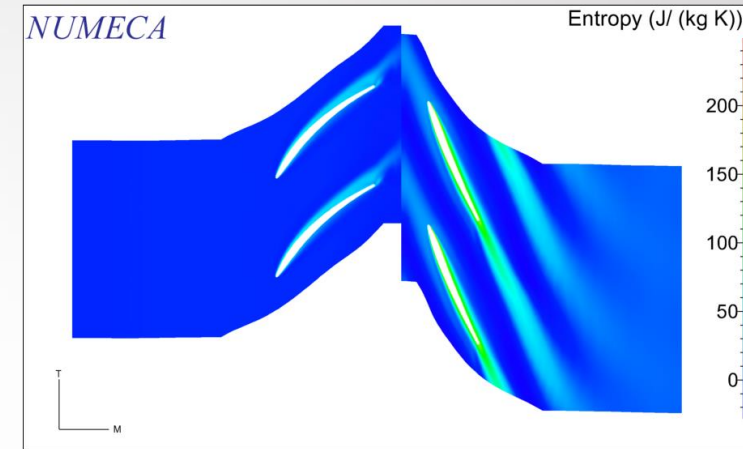
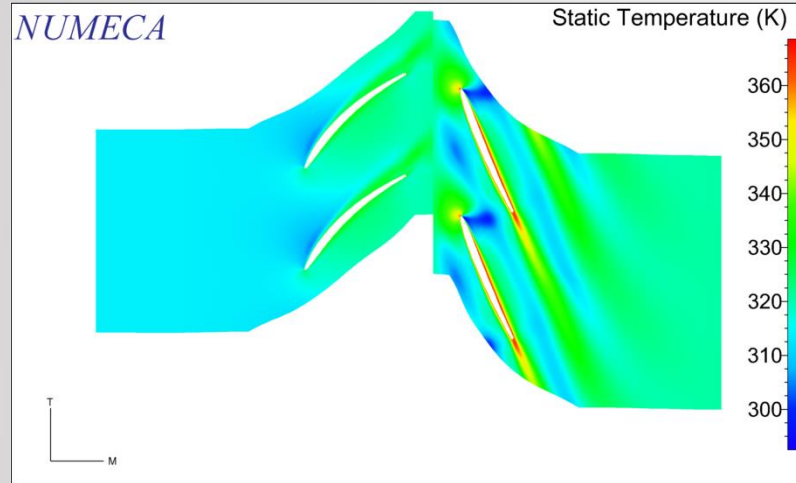
Mass flow

Mass_flow	0.29991	0.30125	[kg/s]
Absolute_Mass_flow (Different in case of backflow)	0.29991	0.30125	[kg/s]

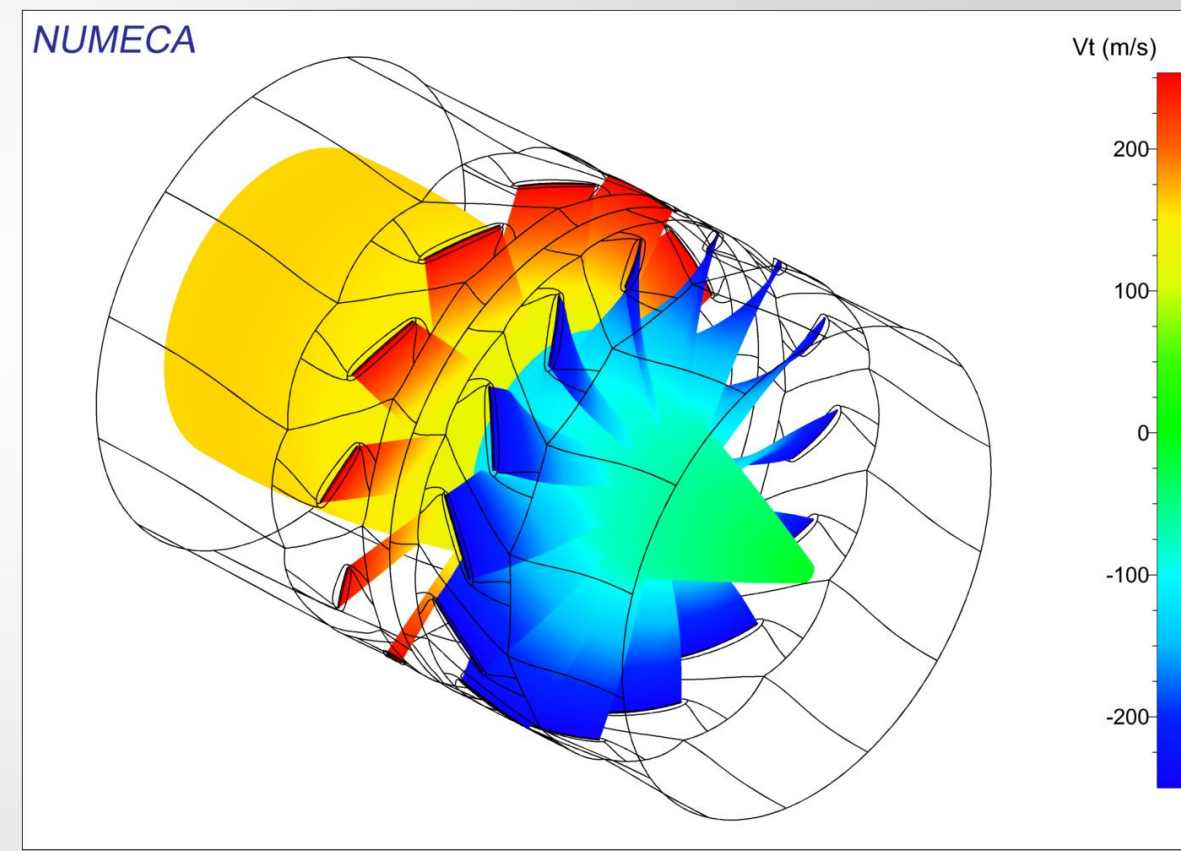
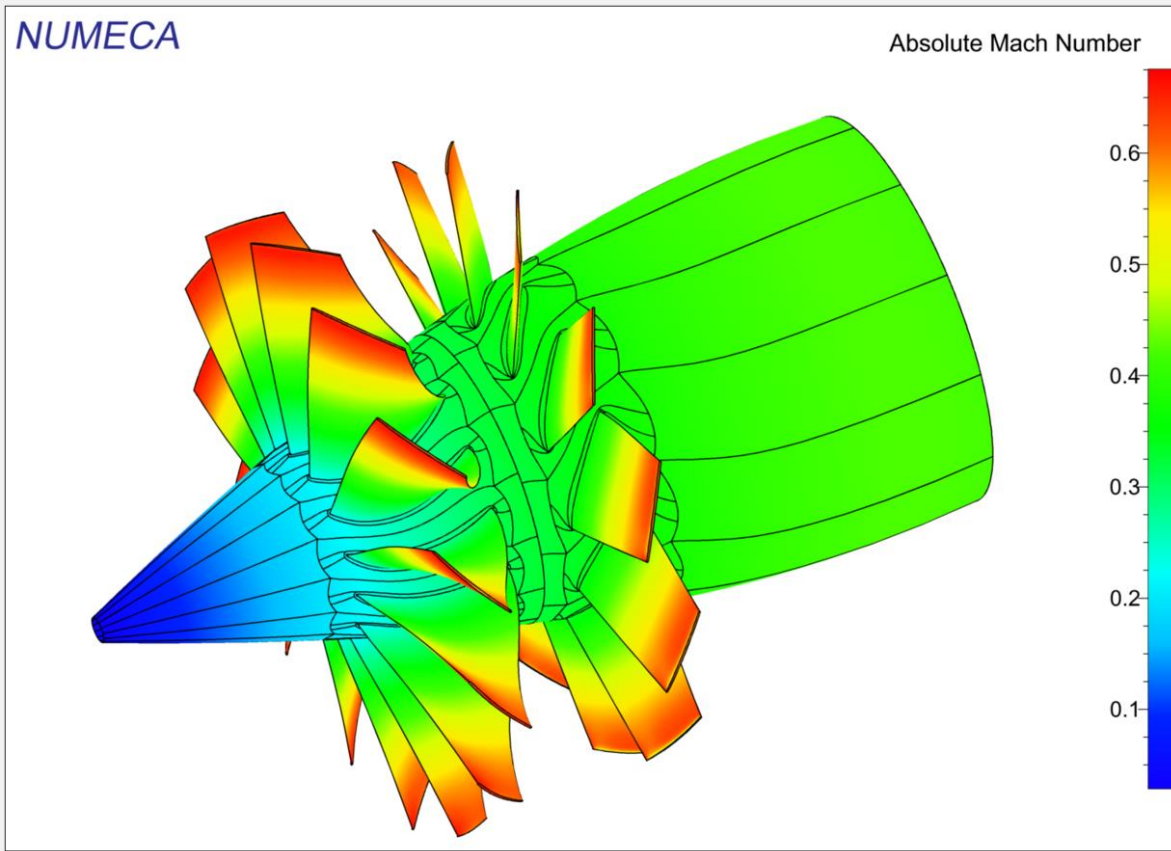
3D CFD of CR Fan



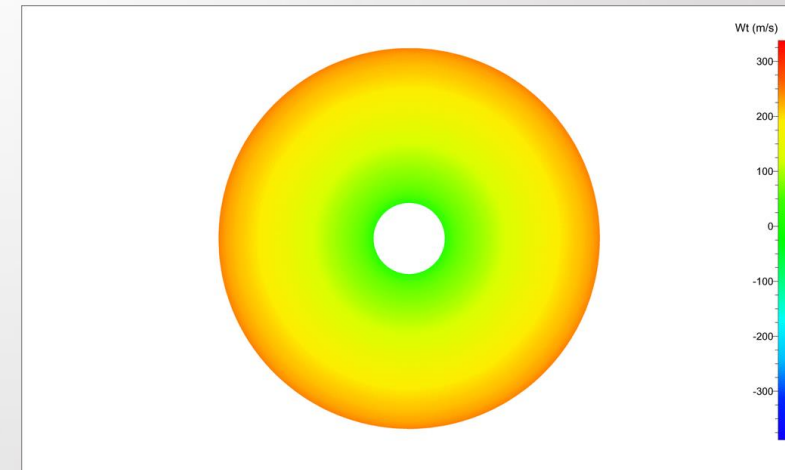
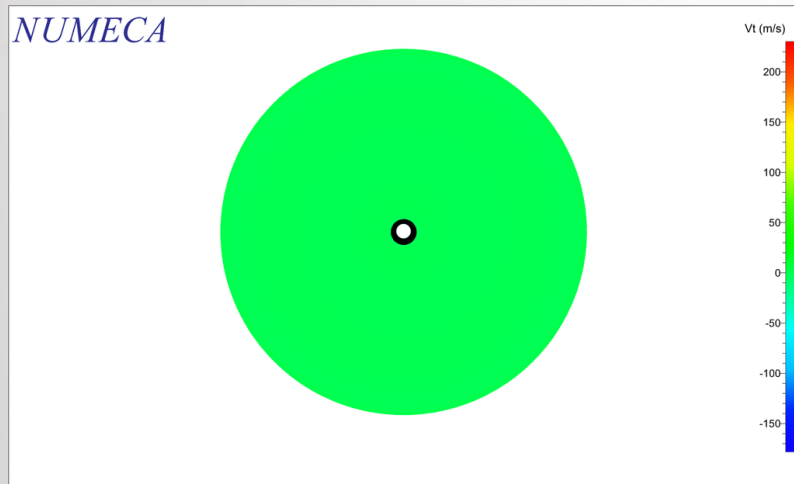
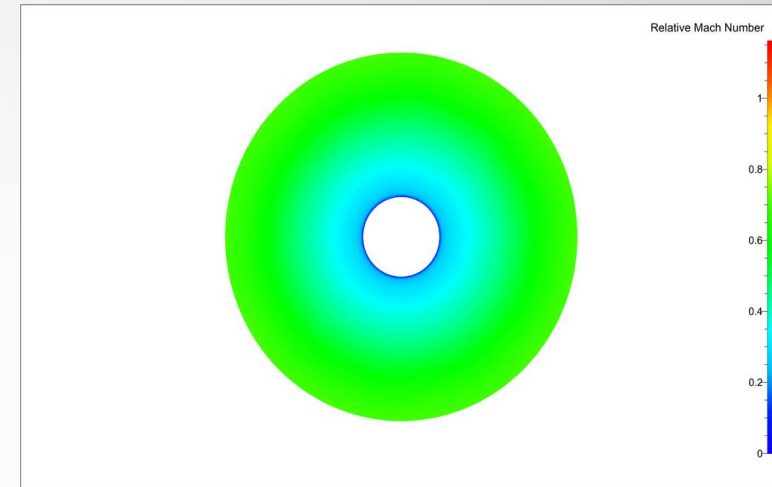
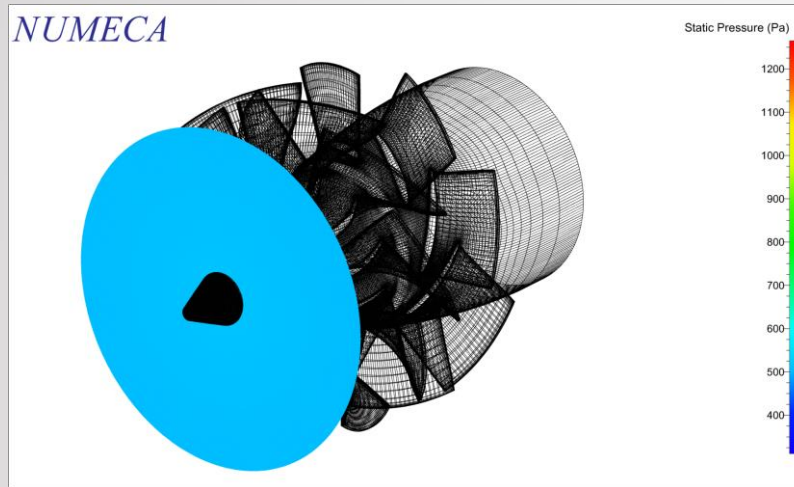
3D CFD of CR Fan



3D CFD of CR Fan



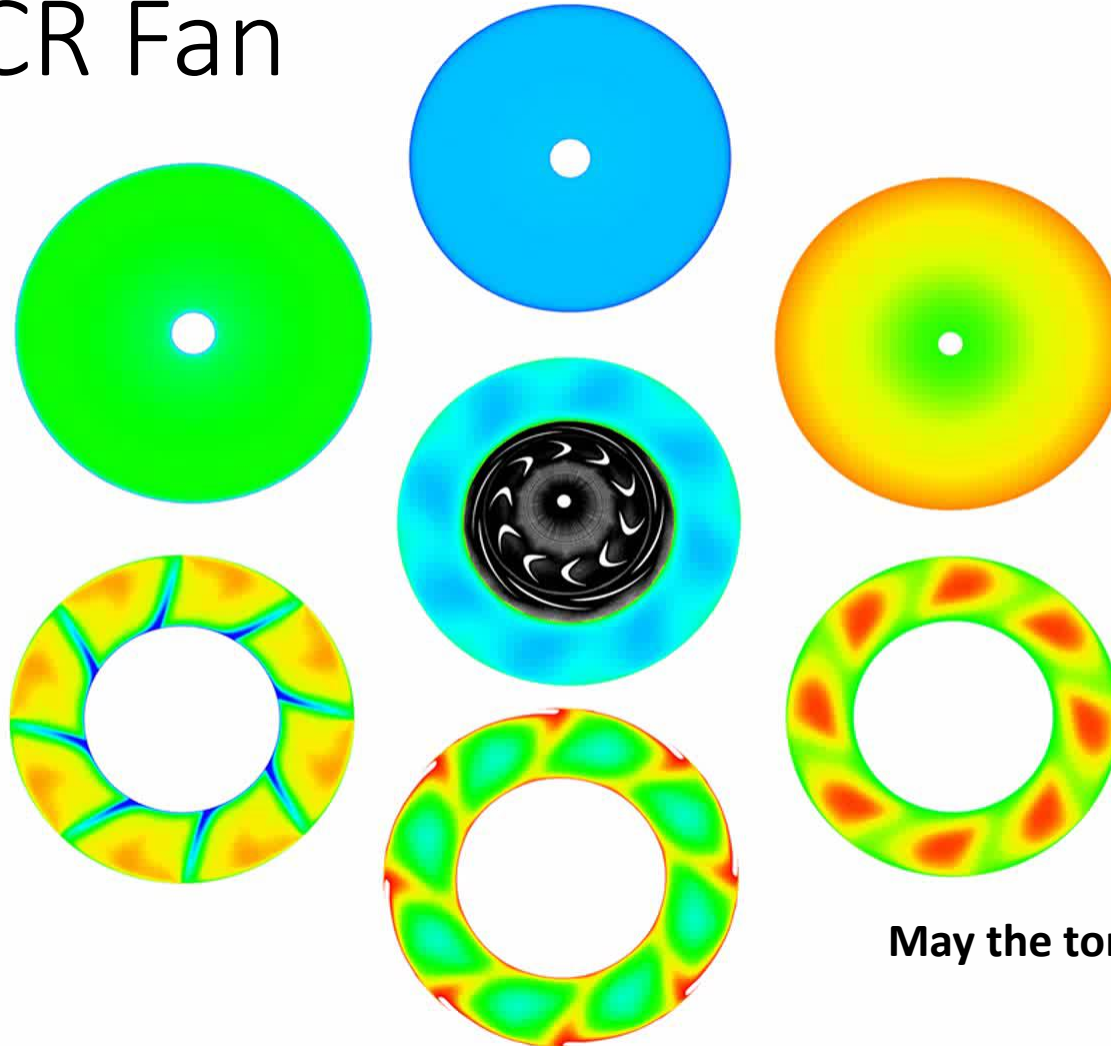
3D CFD of CR Fan



3D CFD of CR Fan

HYPERLOOP **UC**

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Cincinnati

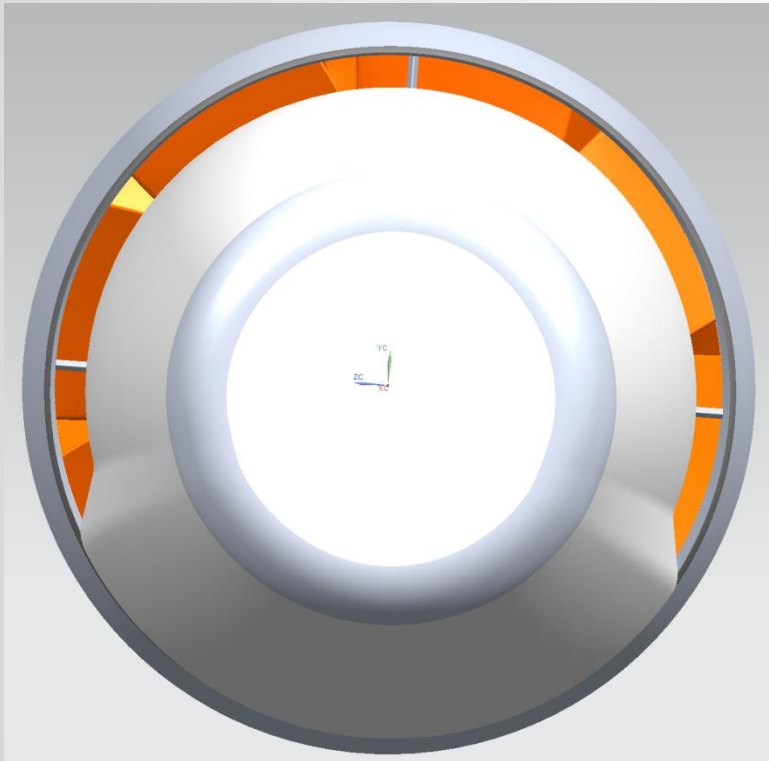


May the torque be with you

Contour plots of aerodynamic properties on cross-flow planes looking head on from inlet to exit are shown here. Absolute Tangential Velocity in the center, clockwise from above it is Total Pressure, Relative Tangential Velocity, Density, Total Temperature, Relative Mach and Absolute Mach.

Transition Duct and Nozzle

- A simple transition duct with increasing area and eventually decreasing area leading to a convergent nozzle is chosen.
- The nozzle is partial annular convergent nozzle.



**Rear View without the Skirt ,
brake wheels and
hoverboard**

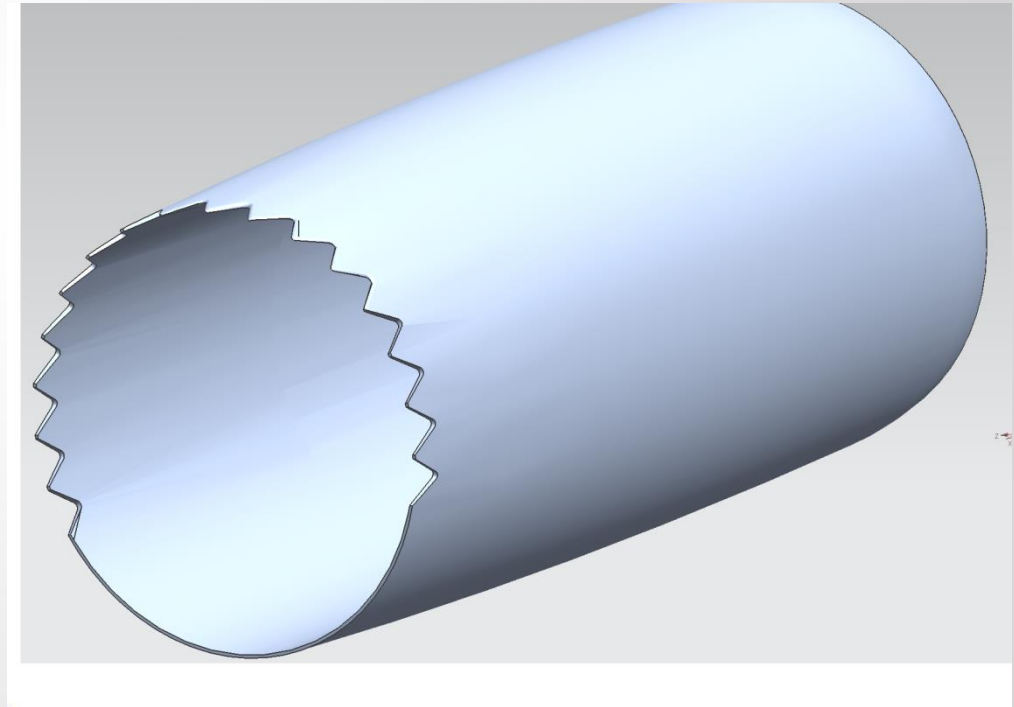
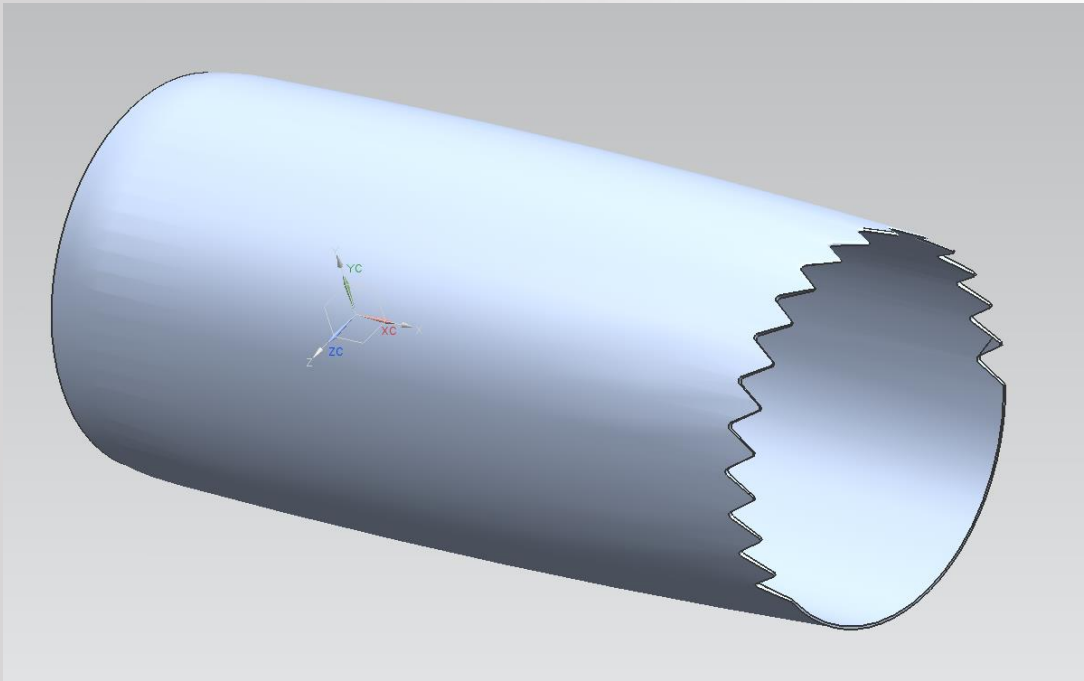
Safety and Scalability

The fan + duct+ nozzle called as 'Engine' is placed in front of the capsule so there will be a separate wall which will act as shield in case of any failure and can detach if necessary from the rest of the pod.

The dimensions will be optimized and scaled if necessary. If scaled a compressor can be added.

Novel Features

- To reduce the noise at the exit of nozzle, chevrons can be used.
- The nozzle is partial annular convergent nozzle.
- Both near and far field noise can be reduced upto 5 dB using chevrons.



**Shroud extended to partial
annular nozzle with chevrons**

References

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